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PV Cell Fed High Voltage Gain DC-DC Converter for Grid Converter Applications

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Abstract- Low voltage photovoltaic systems require highly efficient converters to deliver as much as possible energy to the load with high gain DC voltage conversion. This concept presents two efficient step-up DC/DC converters one composed of five identical phases driven interchangeably and latter partial parallel isolated converter with voltage double. Experimental validation of theoretical assumption and discussion on power losses has been carried out. The use of silicon carbide components and current sharing technique assures high efficiency within wide power range. The proposed concept can be implemented to pv cell fed dc-dc converter for grid connected applications by using Matlab/Simulink software.
Index Terms-DC-DC converter, High step-up, coupled inductor, ground leakage current.

I INTRODUCTION

FOSSIL fuels are an essential source of energy and are applied vastly in recent decades. Unfortunately, usage of fossil fuels has resulted in lots of problems for the environment. Threat of climate change and other similar damages to the environment are now very serious. Now, researchers are motivated to look for clean alternatives for supplying energy [1] and [2].

Renewable energy sources have been found as the best alternative for fossil fuels. Among these clean energy sources, photovoltaic (PY) systems, are considered as the leading technology. In recent years, lots of researches are performed for improving the photovoltaic systems and making these systems more economic [3] and [4]. Also, other alternatives like fuel cells are studied and are considered as clean and potential sources.

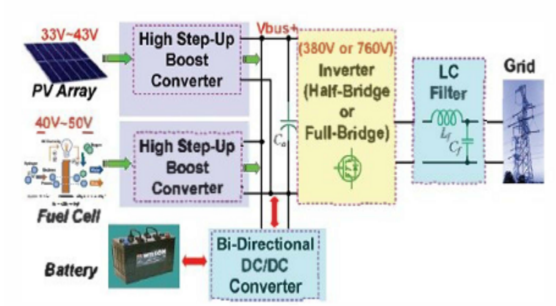

Fig 1 Diagram of a single-phase renewable energy grid-connected system

The improvements within renewable energy systems include improvements in energy conversion systems, such as PY arrays and fuel cells, and improvements in electrical circuits for managing the generated power. Fig.3.1 shows a hybrid renewable energy grid-connected system. The main challenges within designing these renewable systems are: efficient extracting electrical power from the energy conversion system and converting the generated power to the desired level and form. For instance, for the renewable energy system shown in Fig.3.1, the maximum possible generated power by the PY array must be extracted by the following power converter and then the low voltage of the PY module should be converted to a much higher voltage needed by the next block. Therefore, two important duties of the high step-up converters in Fig 1 are: Maximum Power Point Tracking (MPPT) and boosting the low generated voltage by PY array and fuel cell. So far, lots of researches are carried out to improve the efficiency, reliability, cost and life span of the DC-DC converters for renewable energy sources [1-10]. In [1-6] many DC-DC and DC-AC converters for this purpose are reviewed. For this application, conventional boost converter will be the first choice. But for the simple boost converter, the voltage stress of the switch and diode are equal to the high output voltage, where high-voltage rated components with high on-resistance should are used, which causes high conduction losses. Moreover, in high duty cycles, high conduction losses and serious reverse recovery problems are caused. Hence, in the conversion ratios of more than 7 conventional boost converter is not a reasonable choice.

So far, lots of research carried out to achieve a high- efficiency, high-conversion ratio converter without extremely high operating duty cycle [10]-[32]. The quadratic boost converter is an interesting topology for extending conversion ratio which uses only a single active switch [10]-[12], where the voltage conversion ratio is a quadratic function of a conventional boost converter. However, voltage stress of the switch in these converters is equal to the output voltage thus a high-voltage and high current switch should be selected.

Three-level boost converter can double the voltage gain and halve components voltage stress compared with the conventional boost converter [14] and [15]. Lower voltage rated MOSFETs with lower on resistance can be employed to reduce associated loss with switching and conduction the circuit cost and the conduction losses due to the low voltage stress. However, the converter operates under a hard -switching condition, and the output diode reverse-recovery problem is troublesome. In [16] and [19] switched capacitors are used to achieve high step up conversion ratio converter. However, in these converters as voltage gain increases number of required components increase, which results in higher cost. Also, high switching losses and current stress are troublesome too.

Some converters based on transformers or coupled inductors are presented in [20]- [3 3] to achieve high conversion ratio without extremely high duty cycle. The conventional fly back converter can achieve high voltage conversion ratio only by adjusting the turn ratio of the transformer but, the leakage inductance of the transformer cause high voltage spikes on switch, increases switching losses. In order to solve this problem passive resistor -capacitor-diode RCD snubber can be used, but the leakage inductor energy will be dissipated. Although active auxiliary circuit can clamp voltage spikes and recycle leakage inductor energy [27] but additional active switch complicates structures and control.

In this paper a novel DC-DC converter with high gain is presented. Using a low voltage MOSFET switch in this topology, results in lower switching losses and also, easier control method to achieve MPPT. High voltage gain of the first stage makes it suitable for renewable energy systems in which a high boost ratio is required to amplify the low DC voltage of PY module to adequate DC level for grid -connected inverter. Moreover, it is claimed that in the proposed topology the unwanted ground leakage currents in PY systems, which is due to wide surface of PY modules, is reduced drastically [7]. This is because of bipolar outputs of the DC-DC converter which provides a neutral point for connecting the negative terminal of the PY module to this point.

The proposed high step-up converter topology and its experimental results of a developed 100 watt prototype are presented.

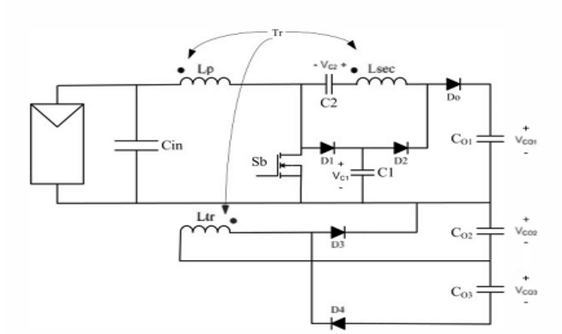

Fig 2 Proposed High Step-Up Converter.

II CIRCUIT CONFIGURATION AND ANALYSES

The proposed DC-DC converter is depicted in Fig.3.2. This converter is a high step-up boost converter with coupled inductors. Switch S_b is the main switch. L_p, L_{sec}, and L_{tr} represent individual inductors in the primary, secondary and tertiary sides of the coupled inductor (T_r). Diodes D and D_2 and capacitor C, form the passive regenerative clamp circuit. C_2isa high voltage capacitor and is located in series with secondary side of the coupled inductor. D_o, D_3, D_4, C_{Ol}, C_{O2} and C_{03} are output diodes and filter capacitors.

Primary and secondary sides of Tr along with capacitor C2 and snubber circuit form a high step-up boost converter and

tertiary side of Tr along with diodes D3 and D4 form a combination of a DCM forward and a fly back converter.

In this section, the detailed operational modes of the DC-DC converter are described in section 3.2.1, and then the converter is analyzed in section 3.2.2. The key wave forms of the DC-DC converter and its operational modes are depicted in Fig.3.3 and Fig.3.4.

a) OPERATIONAL MODES: In order to simplify the circuit analysis, all electronic devices are considered ideal. The coupled inductor is modeled with an ideal transformer, a (L1k), and a magnetizing inductor (L_m). Turns ratios and coupling coefficient are defined as:

$$n_1 = N_2 / N_1 \tag{3.1}$$

$$n_2 = N_3 / N_1 \tag{3.2}$$

$$k = L_m / (L_{lk} + L_m) \tag{3.3}$$

where N" N2 and N3 are the winding turns of the primary, secondary, and tertiary sides of the coupled inductor.

1) Mode1 (t_o- t_l) [Fig 3 (a)]:

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When switch S_b is turned on, the magnetizing inductor is charging by the input voltage and its current is increasing linearly. Diode D_3 is on and the tertiary current (i_{D3}) is increasing because of the voltage difference between the capacitor C_{O2} and tertiary side which is established across the leakage inductor in tertiary side. Proportionally the current through secondary side is increasing. Hence, the secondary voltage in series with clamp voltage (V_{Cl}), charge the capacitor C_2.

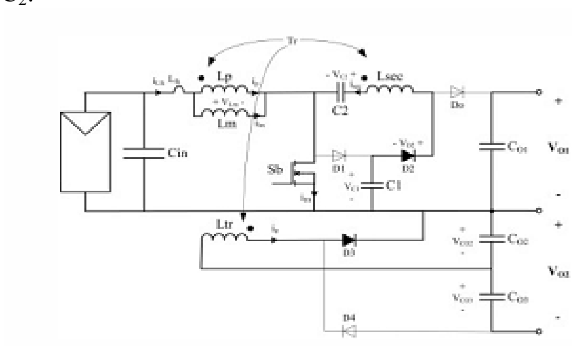

Fig 3 (a) mode 1

2) Mode 2 (t_1 - t_2) [Fig 3 (b)]:

When switch Sb turns off, the leakage current along with secondary current charge the drain-source capacitor of the S_b and then diode D_1 is turned on and the leakage and secondary currents start to charge the clamp capacitor C_1. Meanwhile, the current through leakage inductor decreases until equals to the current through magnetizing inductor, and then the current through primary, secondary and tertiary sides become zero.

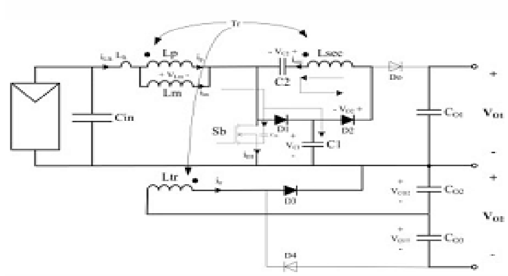

Fig 3 (b) mode 2

3) Mode 3 (t_2 - t_3) [Fig 3 (c)]:

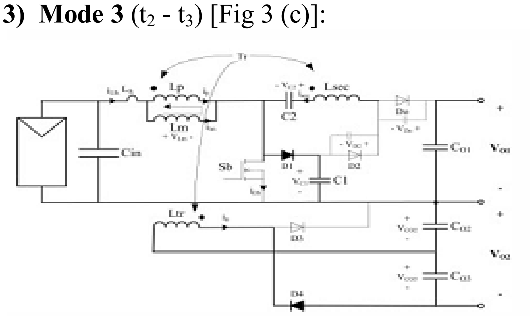

Fig 3 (c) mode 3

When leakage current becomes lower than magnetizing current, the direction of currents through transformer changes. At this moment, diode D_2 is turned off and the voltage across diodes D_4 and D_o are forced to decay to zero. Due to existence of leakage inductor, these diodes are switched under fully soft -switching condition.

4) Mode 4 (t_3 -t_4) [Fig 3 (d)]:

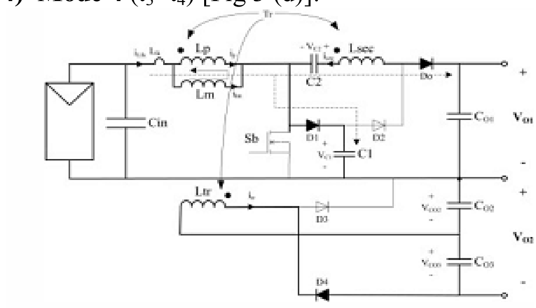

Fig 3 (d) mode 4

Once diode Do turns on, the series voltages of input source, capacitor C_2, leakage inductor, magnetizing inductor and secondary side supply output capacitor C_{Ol}. Also, by conduction of D_4, the output capacitor C_{03} is charged by the current through tertiary side of transformer. Meanwhile, the leakage current is still charging the clamp capacitor C_1. During this mode, the clamp capacitor is charged, the diode D_l turns off and leakage current equals to the secondary current.

5) Mode 5 (t_4 -t_5) [Fig 3 (e)]:

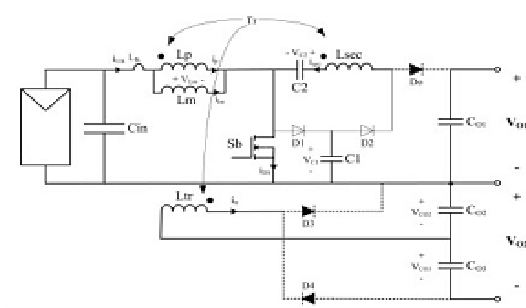

Fig 3 (e) mode 5

At the beginning of this mode, since the leakage current and the secondary current are equal, and also due to the limited raising rate of leakage current because of the leakage inductance, the switch Sb turns on under Zero current switching condition (ZCS). After Sb is tuned on, the leakage inductor is charged until its current reaches the magnetizing current and then becomes greater. Meanwhile the current through primary side of T_r becomes zero and then increases in the reverse direction. This change in the current through transformer causes the diodes D_o and D_4 turn off and then the diodes D_3 and D_2 turn on.

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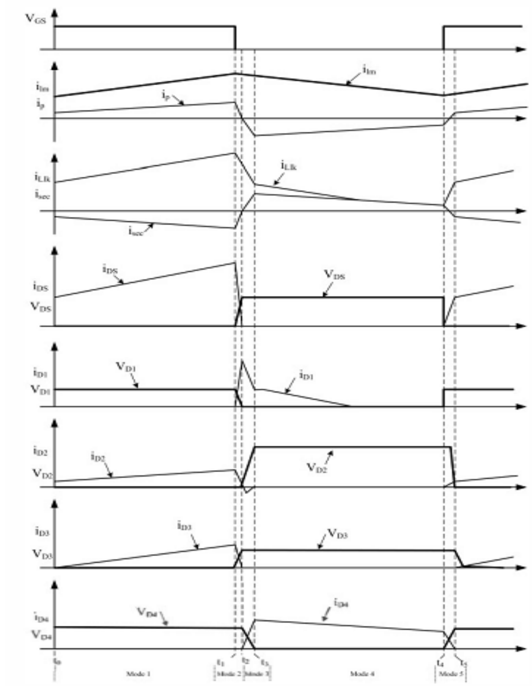

Fig 4. Key theoretical waveforms of the proposed converter

b) CONVERTER ANALYSIS: In this part, the voltages of output capacitors are derived. To simplify the analysis, coupling coefficient of the transformer T_r is assumed unity. The magnetizing inductor of the transformer along with switch S_b, diode D_1 and capacitor C_1, form a conventional boost converter and like any boost converter in CCM mode, the voltage of capacitor C_{P1} can be calculated as:

$$V_{C1} = \frac{V_{in}}{1-D} \tag{3.4}$$

Where D is the duty cycle. The voltage across secondary side of the transformer is n_1 times of the input voltage and the series voltages of secondary side and capacitor C_1 charge the capacitor C_1. So the voltage across C_1 can be calculated as:

$$V_{C2} = n_1.V_{in} + \frac{V_{in}}{1-D} \tag{3.5}$$

When switch S_b turns off, the primary and secondary sides of the transformer along with capacitor C_2 charge the capacitor C_{Ol} and the following KVL is established:

$$V_{Col} = V_{in} - V_p + V_{C2} - V_{sec} \tag{3.6}$$

where V_p and V_{sec} are the voltages of the primary and secondary sides respectively. By (3.4), (3.5) and (3.6) the voltage of capacitor C_{Ol} is derived as:

$$V_{CO1} = \frac{2+n_1}{1-D} V_{in} \tag{3.7}$$

When switch Sb turns on, the capacitor C_{O2} is charged through the diode D_3 and tertiary side of transformer. The difference voltage between tertiary side and the voltage of capacitor C_{O2} is located across the leakage inductor in tertiary side and forms a current that charges C_{O2} up to the tertiary voltage (assuming the coupling coefficient unity). Thus the voltage of capacitor C_{O2} can be calculated as:

$$V_{C_{O2}} = n_2.V_{in} \tag{3.8}$$

The capacitor C_{03} along with the tertiary side and the diode D_4 form a fly back converter and when the switch Sb is off, the capacitor C_{03} is charge. Therefore, like any fly back converter in CCM mode, the voltage of capacitor Cm can be expressed as:

$$V_{C_{O3}} = n_2.V_{in} \frac{D}{1-D} \tag{3.9}$$

The sum of capacitors C_{O2} and C_{03} voltages form one of the converter outputs and can be expressed as:

$$V_{O2} = V_{C_{O2}} + V_{C_{O3}} = n_2.\frac{V_{in}}{1-D} \tag{3.10}$$

III DESIGN CONSIDERATION

If this converter is used for extracting power from a photovoltaic module, an MPPT algorithm must be used to control the converter. Since the proposed converter has a single-switch, implementation of MPPT algorithm is simple.

The difference voltage between capacitor CO2 and the voltage of tertiary side, which is a relatively high voltage at the converter start up time, would be applied across the leakage inductor in the tertiary side and leads to a high current that can damage the main switch. Therefore, to avoid this high current at the starting, a soft-start must be considered for the control block.

If used for grid-connected applications, the output capacitors of the converter may have the roll of power decoupling capacitor. So, the minimum value of the output capacitors can be calculated as:

$$C = \frac{P}{2.\omega_{grid}.V_C.\Delta v_C} \tag{3.12}$$

where P is the nominal power of PV module, ω_{grid} is the grid angular frequency, V_c is the mean voltage across the capacitor and ΔV_c is the amplitude of voltage ripple [1].

By choosing a larger magnetizing inductor, the input current variations can be reduced and consequently a smaller input capacitor in parallel with the PV -module would be required. However, a large magnetizing inductor increases the volume, price and cost of the circuit.

A fast conductive device must be chosen as the clamp diode (D_1) which its voltage stress is equal to the voltage stress of switch S_b. Schottky diodes are better choice for this purpose.

IV PV WITH GRID CONNECTION

This paper presents a single-phase five-level photovoltaic (PV) inverter topology for grid-connected PV systems with a novel pulse width-modulated (PWM) control scheme. Two reference signals identical to each other with an offset equivalent to the amplitude of the triangular carrier signal were used to generate PWM signals for the switches. A digital proportional-integral current control algorithm is implemented in DSP TMS320F2812 to keep the current injected into the grid sinusoidal and to have high dynamic performance with rapidly changing atmospheric conditions. The inverter offers much less total harmonic distortion and can operate at near-unity power factor. The proposed system is verified through simulation and is implemented in a prototype, and the experimental results are compared with that with the conventional single-phase three-level grid-connected PWM inverter.

A **grid-connected photovoltaic power system** or **grid-connected PV system** is an electricity generating system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load,

Residential, grid-connected rooftop systems which have a capacity more than 10 kilowatts can meet the load of most consumers. They can feed excess power to the grid where it is consumed by other users. The feedback is done through a meter to monitor power transferred. Photovoltaic wattage may be less than average consumption, in which case the consumer will continue to purchase grid energy, but a lesser amount than previously. If photovoltaic wattage substantially exceeds average consumption, the energy produced by the panels will be much in excess of the demand. In this case, the excess power can yield revenue by selling it to the grid. Depending on their agreement with their local grid energy company, the consumer only needs to pay the cost of electricity consumed less the value of electricity generated. This will be a negative number if more electricity is generated than consumed.[3] Additionally, in some cases, cash incentives are paid from the grid operator to the consumer Connection of the photovoltaic power system can be done only through an interconnection agreement between the consumer and the utility company. The agreement details the various safety standards to be followed during the connection.

V MATLAB/SIMULATION RESULTS

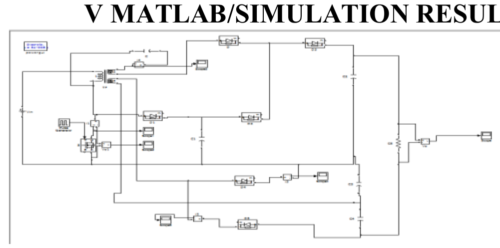

Fig 5 Matlab/simulation circuit of a single-phase renewable energy system

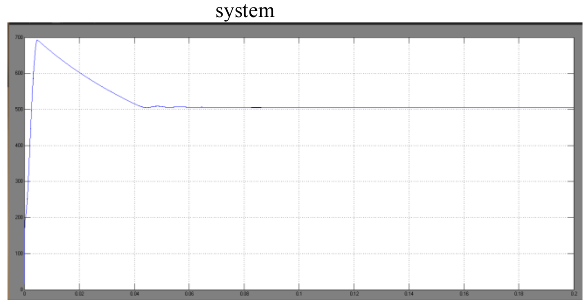

Fig 6 simulation wave form of single phase output voltage

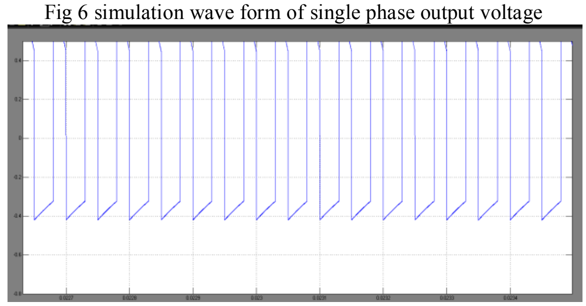

Fig 7 simulation wave form of single –phase transformer current

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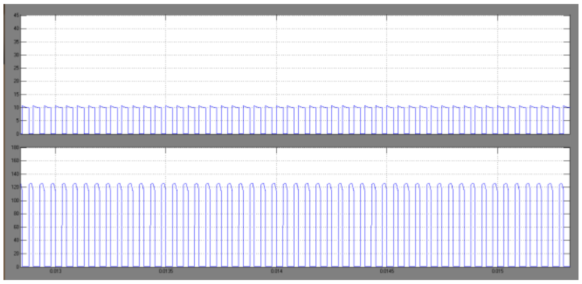

Fig 8 simulation wave form of switching voltage and current

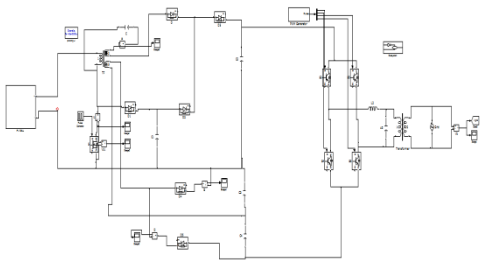

Fig 9 5 Matlab/simulation circuit of a single-phase renewable energy system is connected to grid

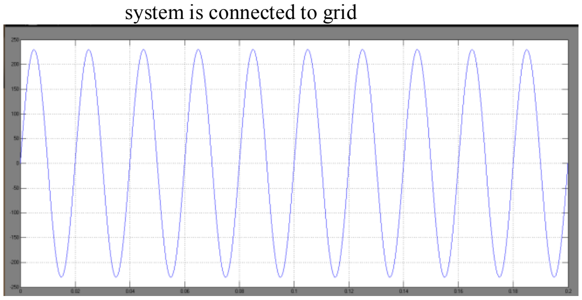

Fig 10 simulation wave form of a single-phase renewable energy system is connected to grid output voltage

VI CONCLUSION

In this paper a new high step-up DC-DC converter suitable for photovoltaic application is presented. Due to the single-switch structure, an easy control and efficient MPPT is expected for the proposed converter. Moreover, because a neutral point at the output of the proposed converter is provided and connected to the negative terminal of the PV module, the amount of the ground leakage currents in photovoltaic systems is drastically reduced. High step-up DC-DC conversion in the proposed converter provides the possibility to amplifying the low produced voltage by PV module to reach the high peak voltage required for the inverter stage. Due to the soft switching of the diodes and the switch, a high efficiency is measured for the proposed converter under various output powers is connected to grid .In the grid voltage is maintained effective voltage at grid.

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